REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave Blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	07/19/96	10/01/91 to 03/31/96

4. TITLE AND SUBTITLE
Interpreting the Variability of Near-Surface Optical and Biolgical Properties in Marine Waters.

5. FUNDING NUMBERS
G

N00014-92-J-1099

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Department of the Navy
Office of Naval Research
Boston Regional Office
495 Summer St., Room 103
Boston, MA 02210-2109

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution is unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

The optical properties of surface waters are strongly influenced by biogenic particles, hence by particle dynamics and by changes in cellular optical characteristics. Our principal objective was to describe spatial and temporal variability in water clarity, phytoplankton biomass and particle dynamics in terms of downwelling irradiance and upwelling radiance, measured at the surface in coastal and oceanic waters with newly-developed drifting and moored radiometers. Toward this end, extensive optical and biological sampling was conducted during studies in coastal waters, culminating with a multi-investigator cruise off the coast of Oregon, during which many optical instruments were deployed and evaluated. We demonstrated that a radiomenter buoy provides reliable observations of ocean color, suitable for development of algorithms and for quantifying optical variability in surface waters. We examined the relationships between biological processes and optical properties of the upper ocean and made significant steps toward characterizing the relationships between irradiance, fluorescence, chlorophyll and photosynthesis near the sea-surface. Radiometer buoys have been estabilised as extremely useful tools in optical oceanography.

14. SUBJECT TERMS
Water-leaving radiance, coastal, oceanic, reflectance, diffuse attenuation, photosynthesis, particle dynamics, bio-optical models.

15. NUMBER OF PAGES
6

16. PRICE CODE
- -

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
unclassified	unclassified	unclassified	UL

"Interpreting the Variability of Near-Surface Optical and Biological Properties in Marine Waters."

N00014-92-J-1099

October 1, 1991 to March 31, 1996

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$319,437.00

GOALS

Our principal goal was to describe spatial and temporal variability in water clarity, phytoplankton biomass, and particle dynamics in terms of downwelling irradiance and upwelling radiance, measured at the surface in coastal and oceanic waters.

OBJECTIVES

The major objective was to relate measurements of upwelling radiance at the surface in a variety of coastal waters to profiles of optical properties and biological constituents in the surface layer. The purpose was to describe quantitatively the links between optics and biology in the sea: in particular, we wanted to determine if relatively simple, passive optical measurements can accurately characterize variability in the concentrations and community characteristics (i.e., big cells vs. small; weakly vs heavily pigmented) of phytoplankton that can dominate in coastal waters. We had also hoped to characterize particle dynamics on the basis of diel changes in optical properties of phytoplankton.

APPROACH

Extensive optical and biological sampling was conducted during studies in Bedford Basin, Nova Scotia and the research program culminated with a multi-investigator cruise off the coast of Oregon, during which several newly-developed optical instruments were deployed and evaluated. Our tethered spectral radiometer buoy (TSRB) measured upwelling radiance in 7 wavebands, along with downwelling irradiance at 490 nm. These measurements were analyzed statistically, averaged appropriately, and related to biological variability, as assessed by our characterization of the phytoplankton assemblage with size-fractionated pigments. These data have been exchanged with C. Roesler, who measured dissolved- and detritus-corrected particular absorbance. Flow cytometry (T. Cucci and S. Ackleson) complements the pigment determinations, greatly enhancing

their utility. Estimates of reflectance from TSRB recordings were also compared quantitatively to vertical profiles of spectral diffuse attenuation and upwelling radiance, as measured with a profiling spectral radiometer system. Analysis focuses on describing and explaining how changes in the optical properties of the particle assemblage (absorption and scattering) can influence reflectance (ocean color), beam attenuation, and diffuse attenuation. It is hoped that profiles of spectral absorption and fluorescence excitation/emission (SAFire package; T. Cowles, J.R. Zaneveld, R. Desiderio and WET Labs) and in situ measurements of spectral absorption and beam attenuation (AC-9; Zaneveld, S. Pegau, Roesler, WET Labs) will be incorporated into a collaborative analysis.

TASKS COMPLETED

Our optical data have been integrated into our data base of upwelling radiance, downwelling irradiance and near-surface chlorophyll in coastal waters. Algorithms are being evaluated to detect regional and temporal variability as well as the influence of ambient irradiance on solar-induced fluorescence yield. Samples for size-fractionated pigments were analyzed by HPLC. The optical and pigment data are now being shared with our collaborators, and an integrated analysis is proceeding. Meantime, results have been reported in a number of publications and presentations.

RESULTS

We have demonstrated that the TSRB provides reliable observations of ocean color, suitable for development of algorithms and for describing optical relationships quantitatively in surface waters. Comparisons between coastal regions showed expected differences in the relationships between reflectance ratios and near-surface pigment, due principally to the influence of dissolved organic matter and suspended solids. Ratios of blue:green upwelling radiance were shown to be good predictors of water clarity (i.e., diffuse attenuation at 490 nm), consistent with the empirical relationship described by Austin and Petzold, and also extending its validity to much more turbid waters. Large differences in phytoplankton community structure had a relatively weak influence on this relationship for waters off Oregon. Solar-induced fluorescence was a good indicator of chlorophyll in coastal waters. However, the measure was compromised in particularly muddy waters. The relationship between ambient irradiance and solar-induced fluorescence yield showed patterns that can be compared to measurements from the open ocean (Cullen and Lewis 1995) and interpreted in a physiological context when more data are available. Advection and patchiness in coastal waters prevented us from characterizing particle dynamics on the basis of diel changes in the optical properties of phytoplankton. Analysis of data from the laboratory and field showed that the approach has merit for waters less influenced by advection.

ACCOMPLISHMENTS

Very simple and relatively inexpensive optical measurements were shown to yield extremely useful information for characterizing optical and biological variability in coastal waters. The TSRB is particularly well suited for collaborative studies of ocean optics, because it can measure ocean color continuously while more sophisticated measurements are being made in vertical

profile and while the particle assemblage is being sampled intensively. Consequently, we have been able to examine the relationships between biological processes and optical properties of the upper ocean, testing ideas about the influence of community structure on the relationships between reflectance and diffuse attenuation. Because the TSRB measures solar-induced fluorescence continuously during biological and optical studies, we have made significant steps toward characterizing the relationships between irradiance, fluorescence, chlorophyll and photosynthesis near the sea-surface.

Refereed publications:

Cullen, J.J., P.J. Neale, and M.P. Lesser. 1992: Biological weighting function for the inhibition of phytoplankton photosynthesis by ultraviolet radiation, Science, 258, 646-650.

Lohrenz, S. E., D. A. Phinney, J. J. Cullen, C. S. Yentsch and D. B. Olson. 1993: Pigment and primary production distributions in a Gulf Stream meander, J. Geophys. Res., 98 (C8), 14,545-14,560

Ackleson, S.G., J.J. Cullen, J. Brown and M. Lesser. 1993: Irradiance-induced variability in light scatter from marine phytoplankton in culture, J. Plankton Res., 15, 737-759.

Pena, M.A., M.R. Lewis and J.J. Cullen. 1994. New production in the warm pool of the tropical Pacific Ocean. J. Geophys. Res. 99: 14,255-14,268.

MacIntyre, H.L. and J.J. Cullen. 1995. Fine-scale vertical resolution of photosynthetic parameters in a shallow-water benthos. Mar. Ecol. Prog. Ser. 122: 227-237.

Cullen, J.J. and M.R. Lewis. 1995. Biological processes and optical measurements near the sea-surface: some issues relevant to remote sensing. J. Geophys. Res. 100 (C7): 13,255-13,266.

Cullen, J.J. 1995. Status of the iron hypothesis after the open-ocean enrichment experiment. Limnol. Oceanogr. 40: 1336-1343. (invited)

Richardson, T.L., A.M. Ciotti, J.J. Cullen, and T.A. Villareal. 1996. Physiological and optical properties of Rhizosolenia formosa (Bacillariophyceae) in the context of open-ocean vertical migration. J. Phycol. (in press)

Submitted to refereed publications:

Cullen, J.J., A.M. Ciotti, R.F. Davis, and M.R. Lewis. 1996. Optical detection and assessment of algal blooms. Limnol. Oceanogr. (invited: in revision)

Pena, M.A., J.J. Cullen, W.G. Harrison and M.R. Lewis. 1996. The effect of fluctuations in the input of nitrate on phytoplankton biomass and new production. J. Plankton Res. (in revision)

Foley, D.G., T.D. Dickey, M.J. McPhaden, R.R. Bidigare, M.R. Lewis and C. Garside 1995: Time series observations of physical, bio-optical and geochemical properties in the central equatorial Pacific Ocean at 0 deg, 140 deg W November 1991 - April 1993. Deep-Sea Res.

MacIntyre, H.L. and J.J. Cullen 1995: Primary production by suspended and benthic microalgae in a turbid estuary: Time-scales of variability in San Antonio Bay, Texas, Mar. Ecol. Prog. Ser. (in revision)

Invited presentations at conferences:

Cullen, J.J., and M.R. Lewis. 1992: Using optical measurements from near the surface to describe biogeochemical processes in the sea, ASLO Aquatic Sciences Meeting, Santa Fe, NM.

Lewis, M.R. 1992: The influence of variations in the optical properties on the thermal structure of the upper ocean, Autonomous Bio-optical Ocean Observing Systems Scientific Symposium, Monterey, CA.

Cullen, J.J., 1992 ASLO Aquatic Sciences Meeting, Santa Fe, NM (poster), "Inhibition of phytoplankton photosynthesis by ultraviolet radiation: experimental methods for quantitative assessment."

Cullen, J.J., 1992 ASLO Aquatic Sciences Meeting, Santa Fe, NM, "Using optical measurements from near the surface to describe biogeochemical processes in the sea."

Cullen, J.J., 1992 Meeting on Photosynthetic Responses to the Environment, Kona, HI, "Quantifying the Effects of Ultraviolet Radiation on Aquatic Photosynthesis."

Cullen, J.J., 1993 Cullen, J.J., Group for Aquatic Primary Productivity (GAP VI), Saskatoon, Canada, Keynote presentation on modelling.

Cullen, J.J., 1994 Workshop on the Ecology and Oceanography of Harmful Algal Blooms, Winter Park, Colorado, "Detection and Assessment of Harmful Algal Blooms with In Situ Optical Instruments."

Cullen, J.J., 1996 American Geophysical Union / American Society of Limnology and Oceanography Ocean Sciences Meeting, "Optical Observation Technologies and Harmful Algal Blooms."

Cullen, J.J., 1996 Mount Allison University, Sackville, New Brunswick, "Optical Observation of Biological Variability in Surface Waters."

Cullen, J.J., 1996 Guest lecturer for a course on Systems Approach to Biological Ocean Science, University of New Hampshire, Durham.

Cullen, J.J., 1996 Conference: Remote Sensing for Marine Resource Users, Managers, and Educators, Rockport, Maine. "Optical observation technologies for long-term marine monitoring."

Cullen, J.J., 1996 NATO Advanced Study Institute on "The Physiological Ecology of Harmful Algal Blooms," Bermuda. "Special modalities of macronutrient assimilation"

Cullen, J.J., 1996 NATO Advanced Study Institute on "The Physiological Ecology of Harmful Algal Blooms," Bermuda. "Behavior, physiology and the niche of depth-regulating phytoplankton."

Cullen, J.J., 1996 NATO Advanced Study Institute on "The Physiological Ecology of Harmful Algal Blooms," Bermuda. Workshop: "Optical Technologies."
Conference presentations:

McLean, S., A. Ciotti, and M.R. Lewis. 1992: An expendable spectral radiometer (ESR) drifter buoy - field trials, Autonomous Bio-optical Ocean Observing Systems Scientific Symposium, Monterey, CA.

Cullen, J.J., A.M. Ciotti, S.D. McLean and M.R. Lewis 1993: Variability of upwelling spectral radiance near the surface in a coastal embayment. The Oceanography Society Third Scientific Meeting, Seattle.

Lewis, M. R., S. McLean, J. J. Cullen, D. Foley and T. Dickey. 1993. Lagrangian and eulerian observations of optical variability in the equatorial Pacific during JGOFS. The Oceanography Society Third Scientific Meeting, Seattle.

Ciotti, A.M., J.J. Cullen, M.R. Lewis. 1994. Optical characteristics of a red tide. AGU/ASLO Ocean Sciences Meeting, Feb. 1994; EOS 75 (3, Supp): 136.

Cullen, J.J., A.M. Ciotti and M.R. Lewis. 1994. Observing biologically induced optical variability in coastal waters. Proc. SPIE Ocean Optics XII, Bergen, Norway.

Pena, M.A., M.R. Lewis, J.J. Cullen, and W.G. Harrison. 1994. The effect of fluctuation in the input of nitrate on phytoplankton biomass and new production. AGU/ASLO Ocean Sciences Meeting, Feb. 1994; EOS 75 (3, Suppl): 95.

Cullen, J.J., A.M. Ciotti, S. D. McLean, and M.R. Lewis 1995: Detecting algal blooms with passive optical sensors. Seventh International Conf. on Toxic Phytoplankton, Sendai, Japan.

Ciotti, A.M., J.J. Cullen, M.R. Lewis and S.D. McLean. 1996. An empirical study of the influence of phytoplankton size structure on the relationship between surface reflectance and the vertical attenuation of light. AGU/ASLO Ocean Sciences Meeting, San Diego, Feb. 1996. EOS 76 (3): OS113.

Richardson, T.L., A.M. Ciotti, J.J. Cullen, and T.A. Villareal. 1996. Physiological and optical properties of Rhizosolenia formosa (Bacillariophyceae) in the context of vertical migration. EOS 76 (3): OS62.

Technical reports:

Cullen, J.J., R.J. Geider, J. Ishizaka, D.A. Kiefer, J. Marra, E. Sakshaug and J.A. Raven. 1993: Toward a general description of phytoplankton growth for biogeochemical models, In G. Evans [ed.], Toward a Model of Biogeochemical Ocean Processes, Plenum, 153-176.

Cullen, J.J., A.M. Ciotti, and M.R. Lewis 1994: Observing biologically induced optical variability in coastal waters, SPIE Ocean Optics XII, 2258, 105-115.

Awards and honors

Editorial Board, Journal of Marine Systems (1990 - 96) Editorial Board, Journal of Plankton Research (1990 -).

Member, SCOR Working Group 97, "Physiological Ecology of Harmful Algal Blooms"

Member, Botanical Society of America / Phycological Society of America subcommittees on Global Change and Oceanographic Processes 1992-; Ecology, Physiology and Biochemistry 1993-

The Oceanographic Society Meetings Committee, 1988 - 93
American Society of Limnology and Oceanography Nominating Committee, 1994; Committee Chair, 1995.

Jane MacIsaac Facility for Individual Particle Analysis, Advisory Council Member 1991 - 93.

NATO Advanced Research Workshop, "Towards a model of biogeochemical ocean processes," Bonas, France. Phytoplankton working group chair, invited, 1992.

Editor's Citation for Excellence in Refereeing, Journal of Geophysical Research - Oceans, 1993

Awarded the NSERC/Satlantic Industrial Research Chair in Environmental Observation Technology, Dalhousie University, 1995.